2.5 COMBINED SEWER SYSTEM AND RECEIVING WATER MONITORING

In many cases, existing data will not be sufficient to establish existing baseline dry weather or wet weather conditions. Thus, the next step in the long-term planning process generally will be to develop and conduct a monitoring program to adequately characterize existing conditions, as well as provide the necessary calibration and verification data for system modeling. As stated in the CSO Control Policy, "*The permittee should develop a comprehensive, representative monitoring program that measures the frequency, duration, flow rate, volume and pollutant concentration of CSO discharges and assesses the impact of the CSOs on the receiving waters. The monitoring program should include necessary CSO effluent and ambient in-stream monitoring and, where appropriate, other monitoring protocols such as biological assessment, toxicity testing and sediment sampling*" (II.C.1.c).

This section summarizes the main considerations in the development of a monitoring program and the elements that make up the CSS and receiving water monitoring plans. Because CSO data collection programs are site-specific and varied, providing detailed guidance on "typical" activities is a difficult task. EPA's guidance on monitoring and modeling (EPA, 1995d) addresses these issues in greater detail and provides additional references.

2.5.1 Monitoring Plan Development

The monitoring plan plays a significant role in the CSO planning process. Because CSO control decisions are based largely on system characterization (a major element of which is monitoring data), the data obtained must represent the conditions throughout the CSS and receiving water accurately. A well-developed monitoring plan is essential whether the collection of monitoring data is for NMC implementation, LTCP development and implementation, or post-construction monitoring. The municipality should continue to coordinate its efforts with the regulatory authorities (State WQS and watershed personnel, and EPA Regional staff), as well as with other municipalities in the same watershed, throughout the development of the monitoring plan.

The primary goal of any CSO control program is to implement the most cost-effective controls to reduce water quality impacts from CSOs. The monitoring plan will generate data to support decisions for selecting appropriate CSO controls. The monitoring plan might have numerous data collection objectives, depending on local site-specific conditions, some of which are given below:

- Define the CSS's hydraulic response to rainfall.
- Determine CSO flows and pollutant concentrations/loadings.
- Evaluate the impacts of CSOs on receiving water quality.
- Support the review and revision of WQS.
- Support implementation and documentation of the NMC.
- Support the evaluation and selection of long-term CSO controls.

Monitoring is expensive. By tailoring the monitoring program to the CSS, water quality problems and priorities, pollutants of concern, and needs and resources of a community, a balance can be achieved between obtaining sufficient data for system understanding and keeping data collection costs under control. This balance can be achieved and maintained provided that activities between the data collectors and model developers are well coordinated.

To meet the objectives listed above, the data collection program should identify sampling stations, frequency of data collection, and parameters to be monitored. Section 2.5.2 briefly discusses these components for CSS monitoring, as well as techniques and equipment for obtaining rainfall, flow, and pollutant data. Section 2.5.3 follows the same approach for receiving water monitoring.

2.5.2 Combined Sewer System Monitoring

The CSO Control Policy outlines several possible objectives of a CSS monitoring plan:

- Gain a thorough understanding of the CSS

- Adequately characterize the CSS response to wet weather events, such as the number, location, and frequency of the CSOs and the volume, concentration, and mass of pollutants discharged

- Support a mathematical model to characterize the CSS

- Support the development of appropriate measures to implement the NMC

- Support LTCP development

- Evaluate the expected effectiveness of the NMCs and, if necessary, the long-term CSO controls.

The CSS monitoring program should be conducted to satisfy the above objectives as appropriate. For example, the CSO Control Policy specifies that permittees should immediately begin characterizing their CSS and CSOs, demonstrating implementation of the NMC and developing an LTCP. Implementation of the NMC is affected directly by the results of the CSS monitoring program. Monitoring can be performed to support various aspects of the NMC, including maximizing use of the collection system for storage, maximizing flow to the POTW for treatment, and control of solids and floatable materials in CSOs.

2.5.2.1 Selection of Monitoring Stations

An accurate determination of CSO flow, pollutant loadings, and resulting water quality impacts depends on the appropriate and efficient selection of sampling stations. The municipality should select sampling stations strategically so that data collected from a limited number of stations can be used to satisfy multiple monitoring objectives. As mentioned earlier, a thorough examination of the available information on the CSS, its overflow points, field investigation reports, and flow measurements will help in this exercise.

Wet weather discharges can contribute large pulses of pollutant load and might constitute a significant percentage of long-term pollutant loads from combined sewer areas. Wet weather sampling can be used to characterize runoff from these discharges, determine individual pollutant source and total watershed loadings, and assess the impact to receiving waters. The municipality should consider the following criteria when selecting the actual location for CSO sampling (EPA, 1993b):

- **Discharge Volume**—Select sites that constitute a significant portion of the flow from a watershed.
- **Hydraulic Stations**—Spread stations out in interceptors and sewers to define flows; locate at key hydraulic control points, such as pump stations and diversions. Storm water or other source flow data might be required; I/I in the system and entering upstream might need to be defined.
- **Pollutant Stations**—Either based on historical information or deduced from an analysis of land use or population density, select sampling sites to quantify representative or varying pollutant loads (dry versus wet weather quality), sources that affect sensitive areas, and, possibly, non-CSO sources.
- **Geographic Location**—Select sites that permit sampling of flows from major subwatersheds or tributaries to permit isolation of pollutant sources.
- **Accessibility**—Select sites that allow safe access and sample collection.

If possible, the monitoring plan should include some type of flow and pollutant concentration information at every CSO location. Municipalities with small systems and a limited number of overflow points might be able to monitor all locations for each storm event studied. Other municipalities, however, might have budget constraints or a large number of discharge points that make this approach impossible. In such cases, an approach that includes monitoring high priority or critical sites (e.g., the possible criteria outlined previously) with techniques, such as continuous depth and velocity flow monitoring and the use of sampling for chemical analyses, might be appropriate. According to the CSO Control Policy, a "*...representative sample of overflow points can be selected that is sufficient to allow characterization of CSO discharges and their water quality impacts and to facilitate evaluation of control plan alternatives*" (II.C.1). Both the case study, presented after Section 2.5.3.6, and EPA's guidance on monitoring and modeling (EPA, 1995d) present approaches for selecting CSO monitoring sites.

2.5.2.2 Frequency of Monitoring

Municipalities should monitor a sufficient number of storms to support development of hydraulic models or prediction of the CSS response to rainfall events and CSO impacts. The frequency of monitoring should be based on the need to collect data for the development of models or predictions. The data to be collected should be based on model parameters and site-specific considerations, such as the overflow rate, which depends on the rainfall pattern, antecedent dry period, ambient tide or stage of river or stream, and base flow (wastewater and infiltration) to the treatment plant. Monitoring frequency can reflect:

- A certain size precipitation event (e.g., 3-month, 24-hour storm)
- Precipitation events that result in overflows (e.g., more than 0.4 inches of rainfall)
- A certain number of precipitation events (e.g., monitor until five storms are collected of a certain minimum size).

When determining the monitoring frequency, municipalities should consider the following criteria:

- **Frequency of Rainfall/Discharge**—Facilities located in areas where rainfall is more frequent might have more frequent CSOs.
- **Sensitivity of Receiving Waters**—If facilities discharge to sensitive areas or high quality waters, more frequent monitoring might be desirable or warranted. For example, in an area where human contact occurs through swimming, boating, and other recreational activities or where there are intakes for drinking water, more accurate estimates might be needed.
- **Variability of Discharge**—CSOs with variable characteristics should be monitored more frequently than CSOs with relatively consistent characteristics.

The frequency of monitoring should change when the data are used for model verification and later during the post-construction monitoring phase. Information on determining appropriate sampling frequencies can be found in EPA, 1995d, and EPA, 1983.

2.5.2.3 Pollutant Parameters

Chemical analyses generate information about the concentration of pollutants carried in the combined sewage and the variability of these concentrations from outfall to outfall and from storm to storm. Chemical analysis data are used with flow data to compute pollutant loadings to receiving waters. In some cases, such data can also be used to detect the sources of pollutants in the system.

The selection of parameters to be measured during the sampling program should be based on problems identified during the review of existing conditions; the overall goals of the program; the specific objectives of the data collection program; and the requirements of local, State, and Federal regulations. For example, most State WQS have numeric limits for indicator bacteria levels in waters intended for swimming and boating. If local beaches are threatened by bacterial contamination from CSOs or storm water, the program needs to include bacteria sampling.

CSSs need to be monitored for the identified parameters of concern. Parameters of concern should include the pollutants with water quality criteria for the specific designated use(s) of the receiving water and pollutants key to the attainment of the designated water use(s). The CSO Control Policy states: "*Monitoring parameters should include, for example, oxygen demanding pollutants, nutrients, toxic pollutants, sediment contaminants, pathogens, bacteriological indicators (e.g.*, Enterococcus, E. coli), and *toxicity*" (II.C.1.c).

The monitoring plan should also include any other pollutants for which water quality criteria are being exceeded, as well as pollutants suspected to be present in the combined sewage. CSS monitoring should include identified pollutants of concern that are known or thought to be discharged by industrial users in amounts that could affect CSO pollutant concentrations and/or the receiving water. If the water quality criterion for zinc is being exceeded, for example, CSS monitoring for zinc should be conducted in the portions of the CSS associated with significant industrial users that discharge zinc. POTW monitoring data and industrial pretreatment program data on nondomestic discharges can help identify other pollutants expected to be present. In coastal systems, measurements of sodium, chloride, TDS, or conductivity can be used to detect the presence of sea water in the CSS, which can occur because of intrusion through failed tide gates (EPA, 1995d).

2.5.2.4 Rainfall Monitoring and Analysis

Rainfall data are necessary to estimate the amount of runoff generated during a single wet weather event or long-term series of events and for successful hydraulic modeling of the CSS. CSS performance can be predicted by entering rainfall data into a hydrologic/hydraulic model, observing the resulting simulated overflows, and correlating these predicted overflows with measured overflow volumes. There are two general types of rainfall data: (1) continuous rainfall records, obtained either from existing weather stations (often maintained at airports) or from stations set up within the CSS watershed of interest and (2) rainfall frequency data (depth-duration-intensity-frequency analyses of historic rainfall).

For rainfall data collection, the variability in the possible distribution of rainfall over a relatively small area might necessitate a network of rain gages. The number of gages necessary depends on the size of the program, the area, topography, season, and typical characteristics of local rainfall events. EPA has provided guidance for determining rain-gage network density (EPA, 1976a). In addition, the sampling interval is important. The 1-hour data commonly gathered at NOAA gages might underestimate CSO flows by averaging larger peak intensities that occur over shorter time intervals (5- or 15-minute rainfall data might be more appropriate).

Rainfall data can be analyzed using the EPA SYNOP program to develop long-term rainfall statistics, such as depth, intensity, duration, and number of storms. In addition, it might be necessary to develop synthetic rainfall hyetographs for particular design conditions of interest to the program. (Hyetographs are graphs of rainfall intensity versus time, and standard hydrology textbooks contain methods for developing them.) More discussion of rainfall monitoring and analysis can be found in *Combined Sewer Overflows—Guidance for Monitoring and Modeling* (EPA, 1995d).

2.5.2.5 CSO Flow Monitoring and Analysis

Accurate flow monitoring is needed to confirm the hydraulic characteristics of the CSS, provide the necessary calibration and verification data for characterizing rainfall runoff and conveyance, and predict CSO volumes. Selecting the most appropriate monitoring technique often depends on a combination of site characteristics, budgetary constraints, and personnel availability.

Flow measurements are generally made using automatic devices that can be installed in channels, storm drains, or CSO structures. These devices use a variety of sensor types, including pressure/depth sensors and acoustic measurements of stage height or Doppler effects from flow velocity. Data are stored in a computer chip that can be accessed and downloaded by portable computer. Data are processed based on the appropriate pipe, flume, or weir hydraulic equations. Field calibration of data using such equations is important because these types of data can be influenced by surcharging, backwater, tidal flows, and other complex hydraulic conditions typical of wet weather flows. EPA's guidance on CSO monitoring and modeling (EPA, 1995d) provides a matrix and description of the various CSO monitoring methods, including manual methods, primary flow, depth sensing, and velocity meters, as well as advantages and disadvantages of their use in CSS monitoring.

The CSS flow monitoring data can be evaluated to develop an understanding of the hydraulic response of the system. Using this evaluation, the following questions can be answered for the monitored outfalls based on the monitored storms (EPA, 1995d):

- Which CSOs contribute the majority of the flow volume?
- What size storm can be contained by the regulator serving each outfall?
- Does this capacity vary from storm to storm?
- Approximately how many overflows would occur and what would be their volume, based on a rainfall record from a different year? How many occur per year, on average, based on the long-term rainfall record?

Extrapolating from the monitored period to other periods, such as a rainfall record for a year with more storms or larger volumes, requires professional judgment and familiarity with the data. In addition to analyzing total overflow volumes for the CSOs, flow data can be used to develop various graphical and tabular presentations. These could include plots of flow and/or head for a selected conduit during a storm event, as well as tables comparing the relative volumes and activation frequencies from different monitoring sites in the CSS.

2.5.2.6 CSO Quality Sampling and Analysis

Characterization of the CSS requires information on the quality, as well as the quantity, of the overflows. The objective of CSO pollution abatement is to prevent the degradation of receiving water quality from short- and long-term effects of pollutant discharges during wet weather events. It is necessary, therefore, to know the constituents of the overflows and their pollutant loadings.

In general, water sampling methods fall into three categories: grab sampling, flow-weighted sampling, and automated sampling. Grab samples are collected by hand using a container to collect water from the sewer. This method requires minimal equipment and allows field personnel to record additional observations while collecting the sample. Because of their special characteristics, oil and grease, volatile compounds, and bacteria, *must* be analyzed from a sample collected by manual methods according to standard procedures (APHA, 1992).

Data can be obtained by combining multiple grab samples collected throughout a storm event to create a flow-weighted or composite sample. These samples provide data that are representative of the overall quality of combined sewage averaged throughout a storm event. Typically, samples are combined in relation to the amount of flow observed in the period between the samples.

Automated samplers have features that are useful for CSS sampling, such as the ability to collect multiple discrete samples, as well as single or multiple composited samples. They can collect samples on a timed basis or in proportion to flow measurement signals from a flow meter. Although these samplers require a large investment, they can decrease the labor required in a sampling program and increase the reliability of flow-weighted compositing.

In addition, toxicity testing can be used to directly measure, prior to discharge, the acute and chronic impacts of combined sewage on aquatic life. Procedures for toxicity testing are described in *Technical Support Document for Water Quality-based Toxics Control* (EPA, 1991); these procedures can also be used, with caution, for wet weather discharges.

Other important components of any CSO quality sampling effort include sample preservation, handling, and shipping; chain of custody documentation; and quality assurance and quality control (QA/QC) procedures. The QA/QC procedures are essential to ensure that data collected in environmental monitoring programs are useful and reliable. QA refers to program-related efforts to ensure the quality of monitoring and measurement data. QC, which is a subset of QA, refers to the routine application of procedures designed to obtain prescribed standards of performance in monitoring and measurement.

Because data collection programs generate large amounts of information, management and analysis of the data are critical to a successful program. Even small-scale programs, such as those involving only a few CSO and receiving water monitoring locations, can generate an extensive amount of data. EPA's guidance on CSO monitoring and modeling provides examples of data analysis methods (EPA, 1995d).

2.5.3 Receiving Water Monitoring

The objectives of receiving water monitoring generally include the following:

- Assess the attainment of WQS, including designated uses
- Establish the baseline conditions in the receiving water
- Evaluate the impacts of CSOs
- Gain sufficient understanding of the receiving water to support evaluation of proposed CSO control alternatives, including any receiving water modeling that may be needed

- Support the review and revision of WQS.

2.5.3.1 Selection of Monitoring Stations

Municipalities should select monitoring stations for receiving water quality sampling considering the following factors (WPCF, 1989; EPA, 1993b):

- Proximity to discharge sampling locations
- Accessibility
- Safety of personnel and equipment
- Proper location upstream or downstream of incoming sources or tributaries
- Adequate mixing of sources or tributaries at the sampling site.

In addition, municipalities should coordinate the locations with sites that might already have an existing monitoring data base.

To identify sampling locations as part of a receiving water monitoring program, some knowledge of the dynamics of the receiving water is important. In addition to the general criteria listed above, the selection of appropriate locations depends on the characteristics of the receiving water, the pollutants of concern (e.g., bacteria, dissolved oxygen, toxic material), and the location of sensitive areas. The number and placement of sampling locations also depends on the size of the water body, the horizontal and vertical variability in the water body, and the degree of resolution necessary to assess attainment of WQS.

Individual monitoring stations can be located to characterize:

- Pollutant concentrations and loadings from an individual source
- Concentrations and impacts at specific locations, including sensitive areas such as shellfishing beds
- Variations in concentrations between upstream and downstream sampling sites for rivers or between inflow and outflows for lakes, reservoirs, or estuaries

- Changing conditions through time at individual sampling stations
- Differing water bodies or segments that receive CSOs, such as lakes, ponds, rivers, tributaries, bays, or channels
- Effects of other pollution sources within the watershed.

2.5.3.2 *Extent of Monitoring*

Monitoring studies for receiving water characterization should target seasons, flow regimes, and other critical environmental conditions where CSOs have the greatest potential for impacts, as identified in the data investigation (Section 2.4). Based on initial sampling results, the number of stations may be able to be reduced. For example, if initial sampling results show that one of a series of streams within a watershed is of high quality, sampling coverage of this stream could be reduced. Conversely, additional monitoring might be necessary to fill data needs and to support receiving water modeling or to distinguish the relative contribution of other sources to the water quality impairment.

In assessing or demonstrating compliance with WQS, monitoring should provide data designed to answer relevant questions. For instance, to establish a maximum or geometric mean coliform concentration at the point of discharge into a river (or mixing zone boundary, if allowed), grab samples should be taken during and immediately after discharge events in sufficient number (usually specified in the standards) to obtain a reasonable approximation of actual in-stream conditions. On the other hand, assessing attainment of narrative standards to control nutrient load to prevent eutrophication might require the collection of samples through the water body and timed to examine long-term average conditions over the growing seasons. Finally, assessing attainment of narrative standards for the support of aquatic life might require biological assessment in potentially impacted locations and a comparison of the data to reference sites. EPA's guidance on monitoring and modeling describes several examples of receiving water sampling designs, including point-in-time, short-term, long-term, reference site, near-field, and far-field designs (EPA, 1995d).

2.5.3.3 Pollutant Parameters

To assess the impact of wet weather runoff, the water quality of receiving waters during normal dry weather periods should be known. Water quality data collected during dry weather conditions provide a basis of comparison to data collected during wet weather conditions. Sampling several events with varying antecedent dry periods will help define the variations in pollutant loading for the system.

Receiving water monitoring should include identified parameters of concern. These parameters typically include those previously identified for combined sewage and CSO monitoring.

- pH
- BOD
- TDS
- TSS
- Nutrients
- Metals
- Indicator bacteria.

Knowledge of the site-specific water quality concerns could expand the list to include dissolved oxygen, toxics, biological assessment, and sediment.

2.5.3.4 Hydraulic Monitoring and Analysis

Establishing the hydraulic characteristics of the receiving water is an important first step in a receiving water study, since the physical dynamics of the receiving water determine the dilution of pollutants contained in CSOs. Large-scale water movement largely determines the overall transport and transformation of pollutants. Small-scale hydraulics, such as water movement near a discharge point (often called near-field), determine the initial dilution and mixing of the discharge. For example, a discharge into a wide, fast-flowing river might not mix across the river for a long distance. This information can help identify sampling locations in the river to determine CSO effects (EPA, 1995d).

Hydraulic monitoring in receiving waters consists of assessment of transport characteristics (water depth and velocity) and physical characteristics (elevation, bathymetry, cross-section) of the receiving water body. Hydraulic monitoring methods are determined in part based on the type of receiving water being assessed. Generally, gages can be installed on a temporary or long-term basis to determine depth and velocity variations during wet weather.

Analysis of hydraulic data in receiving waters can consist of developing stage-discharge or other rating curves for specific monitoring locations, plotting and reviewing the hydraulic data, pre-processing the data for input into hydraulic models, and evaluating the data to define hydraulic characteristics, such as initial dilution, mixing, travel time, and residence time. Methods for developing rating curves for various types of flow monitoring stations are presented in *Measurement and Computation of Streamflow* (USGS, 1982) and *Water Measurement Manual* (USDI, 1984). The general purpose of these analyses is to allow estimation of the flow rate based on a depth measurement. Calibration of the stage-discharge relationship using measured velocities is necessary.

2.5.3.5 Receiving Water Quality Monitoring and Analysis

The collection and analysis of receiving water quality data are necessary when available data are not sufficient to describe water quality impacts that result from the CSOs. The initial steps in conducting a receiving water sampling program involve selecting sampling locations and determining sampling frequency and parameters (Sections 2.5.3.1 - 2.5.3.3).

Sampling receiving waters to provide background water quality data and to assess CSO impacts can range from manual collection of bacterial samples from a stream to a full-scale oceanographic investigation of a harbor using a sizable vessel and requiring considerable logistics (EPA, 1993b). The use of proper sampling techniques is crucial (USDI, 1984; EPA, 1982; Plumb, 1981; APHA, 1992).

Chemical receiving water quality data are analyzed by plotting and reviewing the raw data to define water quality characteristics and by processing the data for input to water quality models. Data can be analyzed and displayed using various types of spreadsheets, graphics software, and statistical packages. One basic analysis is to compare the receiving water quality data with applicable water quality criteria to determine whether criteria are being exceeded in the receiving water body. Sampling before, during, and after a wet weather event can indicate whether water quality problems occur during dry and/or wet weather and if they are likely due to CSOs or other sources. Sampling data in areas thought to be affected by CSOs can be compared with data from areas upstream of or away from CSO outfalls to try to distinguish CSO impacts. In addition, water quality data are used to calibrate receiving water models usually by plotting the data versus time and/or distance to compare with model simulations (Section 2.6.2). In some cases, special studies might be necessary to identify rate constants, such as bacteria die-off rates or suspended solids settling rates.

2.5.3.6 Sediment and Biological Monitoring and Analysis

It is often difficult and expensive to identify CSO impacts during wet weather using hydraulic and water quality sampling (EPA, 1995d). In some cases, sediment and biological monitoring can serve as cost-effective supplements or even as alternatives to water quality sampling. For example, the long-term effect of CSOs can be represented by comparing grab samples of bottom sediments or biota to data from reference sampling points.

Sediment Sampling

Receiving water sediments serve as sinks for a wide variety of materials. Nutrients, metals, and organic compounds bind to suspended solids and settle to the bottom of a water body when flow velocity is insufficient to keep them in suspension. However, it should be noted that sediments affected by wet weather runoff usually exhibit the long-term effects of both dry and wet weather discharges because of their relative immobility. Grab samples can be taken to indicate historical accumulation patterns. Sampling sites can be located at points of impact, upstream (or downstream) reference sites, areas of future expected changes, or other areas of particular interest, based on an awareness of possible impact sites, accessibility, and hydraulic conditions.

Sediment sampling results are useful for assessment of physical characteristics (grain size, distribution, type of sediment) of the deposited sediments, chemical analysis of sediments deposited by CSOs, and examination of benthic communities that might be affected. Sediments from upstream reference stations, and possibly from areas affected by non-CSO sources, should be sampled for comparison with sediments near the CSO. (It should be noted that sediments affected by CSOs and other wet weather sources may be considerably downstream of the sources, particularly in waters whose velocities increase greatly during rainfall. In general, sediments tend not to settle in streams with velocities greater than 0.5 feet/second.)

Biological Sampling

Evaluating aquatic populations and communities can provide information not available through water and sediment testing. Because resident populations and communities of aquatic organisms integrate over time all the environmental changes that affect them, the biological community can reveal the cumulative impact of pollutant sources or short-term toxic discharges not represented in discrete water and sediment samples. EPA's guidance on monitoring and modeling provides a comprehensive summary of biological collection methods, as well as the information potentially available through the monitoring of aquatic organisms (EPA, 1995d).

Benthic (bottom-dwelling) organisms are affected by contaminants in the water column and through contact with or ingestion of contaminated sediments. Therefore, the type, abundance, and diversity of benthic organisms can be used to investigate the presence, nature, and extent of pollution problems. Comparing areas upstream and downstream of a suspected pollution source requires sampling locations with similar bottom types, because physical characteristics affect the habitat requirements of organisms.

Community structure, described in terms of species diversity, richness, and species evenness, is commonly used to evaluate the environment. The use of biological organisms as indicators of aquatic environmental health is based on the understanding that a natural environment is normally characterized by a balanced biological community comprised of a large number of species with no one species dominating. The presence of certain species that are known to be intolerant of polluted or disturbed conditions may also be used as an indicator of an unstressed environment, and conversely, other species may serve as indicators of environmental stress. Species diversity is affected by such factors as colonization rates, extinction rates, competition, predation, physical disturbance, and pollution, and it is often difficult to determine which factors have caused measured variation in species diversity (i.e., pollution or other conditions). A qualitative data assessment whereby the benthic species collected and their relative population sizes are compared with their known sensitivities to contaminants present, can help with this determination. Various documents describe these assessment techniques (EPA, 1995d; Plafkin et al., 1989).

CASE STUDY: LEWISTON-AUBURN, MAINE—CSO AND RECEIVING WATER MONITORING

Because of the limited CSO and receiving water data available, a full monitoring program was undertaken. The objective of the monitoring program was to collect dry weather (baseline condition) and wet weather data on CSOs, sanitary and separate storm sewer flows, and the rivers and brooks receiving CSOs. These data were then used to quantify pollutant loadings to receiving waters and to assess impacts of those loadings on receiving water quality. The sampling and monitoring data were also used to calibrate and verify computer models of the CSSs in both Lewiston and Auburn (see the case study following Section 2.6.2.3). The different elements of the sampling and monitoring program are summarized below:

- Wastewater flows within each sewer system were measured, sampled, and analyzed for various water quality parameters during dry weather, high ground water (spring time) conditions to determine base wastewater flows, infiltration rates, and baseline pollutant loadings.

- CSOs from four storm events at selected CSO regulators within each CSS were measured, sampled, and analyzed for various water quality parameters during two 6-week periods to determine CSO flows and loads to receiving waters.

- Storm water runoff from four storm events at selected locations within the separate storm drain systems of each city were measured, sampled, and analyzed for various water quality parameters during two 6-week periods to determine pollutant loadings in storm water runoff to receiving waters.

- Receiving waters were sampled and analyzed during dry weather and during two storm events. The collected samples were analyzed for various water quality parameters and priority pollutants to define baseline receiving water quality and to determine the impacts of CSOs on receiving water quality.

- Continuous release dye studies were conducted to assess the rate of mixing and dispersion of CSOs from each city in the receiving waters.

Each of these sampling activities occurred during the same storm events to ensure consistency among the data. The discussions in this case study focus only on the CSO and receiving water sampling.

SELECTION OF CSO MONITORING STATIONS

A review of existing information coupled with a field inspection of the CSSs in Lewiston and Auburn identified a total of 29 CSO regulators and 17 cross-connections between the combined sewer and separate storm drain systems. Because it was not economically feasible to sample and monitor each CSO outfall, site-selection criteria for CSO sampling and monitoring stations were used to select representative CSOs in the study area that were significant contributors of CSO flows to receiving waters.

Initially, the location of each CSO regulator and cross connection in Lewiston was ranked as having a low, moderate, or high frequency of activity. The ranking was determined as follows:

- Low frequency of activity, rainfall greater than 0.75 inches
- Moderate frequency of activity, rainfall between 0.25 and 0.75 inches
- High frequency of activity, rainfall less than 0.25 inches.

Because the CSOs in Auburn were not inspected during all storm events, the data were limited. As a result, a ranking of the frequency of activity during specific rainfall volumes (similar to ranking performed for Lewiston) was not possible. Instead, the frequency of activity between the CSOs for the period that data were available was compared. The criteria used to rank the frequency were as follows:

- Low frequency of activity, 0 to 3 overflows recorded
- Moderate frequency of activity, 4 to 7 overflows recorded
- High frequency of activity, 8 to 10 overflows recorded.

The following final monitoring station selection criteria were developed:

- **Land Use**—The tributary area land uses must be representative of the study area in order to define meaningful rainfall/runoff relationships and pollutant loadings for use in analyzing other tributary areas in the study area.

- **Tributary Area**—An important selection criterion for monitoring CSOs is the ability to define the tributary area boundaries. Tributary areas free of external diversions or transfers were sought to ensure that the flows and pollutants measured at the monitoring site were actually produced within the subbasin being monitored rather than being imported from adjacent service areas or exported out of the subbasin. The tributary areas were identified through detailed study of the sewer systems and topographical maps of the study areas.

- **Hydraulic Compatibility**—The hydraulic control sections at the monitoring stations must be stable and compatible with the proposed monitoring equipment.

- **Accessibility**—The sites should be readily accessible from public rights-of-way and during adverse weather conditions and should be located away from high traffic areas.

- **Receiving Water**—The ecological, social, scenic, or recreational importance of the receiving water where the discharge occurs was considered.

Based on field inspection of CSO regulators and cross-connections, a preliminary screening of potential sampling and monitoring stations was performed using the site-selection criteria. Preliminary screening identified a total of 12 potential locations: 9 in Lewiston and 3 in Auburn (see Exhibits 2-8 and 2-9, respectively).

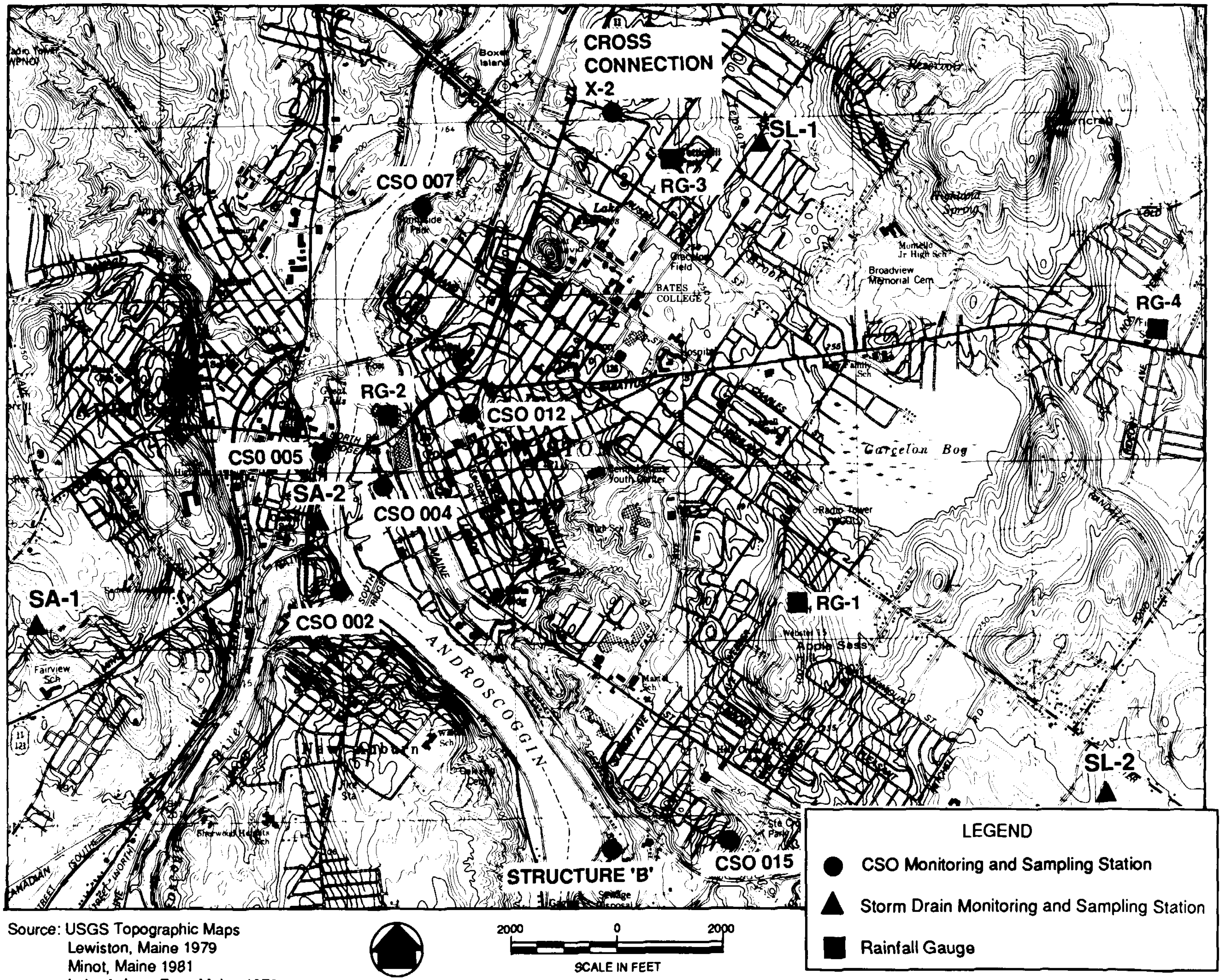
Subsequent to this preliminary screening, field inspections of the potential sampling and monitoring stations were conducted. The purpose of these inspections was to ensure that each location was easily accessible, hydraulically compatible with the equipment to be used, and had a clearly defined tributary area. The eight most advantageous locations were then selected as the final sampling and monitoring stations for CSOs. Exhibit 2-10 shows the locations of the monitoring and sampling locations. As indicated in Exhibit 2-10, these included six CSO regulators in Lewiston (30 percent of the total) and two in Auburn (25 percent of the total). This approach yielded sufficient wet weather data to quantify CSOs in the study area at a reasonable cost.

Exhibit 2-8. Screening of Final CSO Sampling and Monitoring Stations for the City of Lewiston

CSO or Cross-Connection	Advantages	Disadvantages	Selected	Not Selected	Reason Not Selected
003	Overflows frequently, easy accessibility.	Represents mixed land use, small tributary area.		X	Represents small tributary area.
004	Overflows frequently, one of few that serves predominantly commercial/industrial area.	Moderate accessibility due to traffic and ventilation concerns.	X		
005	Overflows to small, stagnant receiving water, potentially large volume of overflow, overflows frequently.	Difficult to monitor CSO flows accurately due to configuration of regulator, potential recreational use of Gully Brook is very limited.		X	Not hydraulically compatible to monitor because it would require at least three flow metering locations.
007	Moderate frequency of overflows, serves predominantly residential area, easy accessibility, medium size service area.	Regulator manhole is shallow making it difficult to install sampling and monitoring equipment.	X		
012	Moderate frequency of overflows.	Represents mixed land use, limited record information on CSO regulator.	X		
013	Overflows frequently.	Represents mixed land use, difficult to monitor CSO flows accurately due to having two tributary regulators.		X	Two flow meters would be required to determine flows and pollutant loads tributary to each regulator.
015	Overflows frequently, represents only CSO discharging directly to Goff Brook, serves predominantly residential neighborhood.	Dry weather flow in Goff Brook is nearly nonexistent, no potential for recreational use.	X		
Structure 'B' @ LAWPCF	Easy accessibility, potentially large volume of bypassed flows, can bypass flow during some plant maintenance procedures.	Represents mixed land use, all CSO regulators in the system are tributary, bypassed flows controlled manually.	X		
X-2	Moderate frequency of overflows, serves predominantly residential neighborhood, discharges to Jepson Brook.	Difficult to monitor CSO flows due to configuration of regulator.	X		

Exhibit 2-9. Screening of Final CSO Sampling and Monitoring Stations for the Auburn Sewerage District

CSO or Cross-Connection	Advantages	Disadvantages	Selected	Not Selected	Reason Not Selected
002	Easy accessibility, discharges to Little Androscoggin River, high frequency of overflows.	Represents mixed land use.	X		
003	Representative of large land area, easy accessibility, discharges to Little Androscoggin River. Moderate frequency of overflow due to plugging of siphon.	Represents mixed land use, overflows infrequently when both siphons operating.		X	Infrequent overflows, difficult to access remote location during off-hours.
005	Easy accessibility, high frequency of overflows.	Represents mixed land use.	X		



Source: USGS Topographic Maps
Lewiston, Maine 1979
Minot, Maine 1981
Lake Auburn East, Maine 1979
Lake Auburn West, Maine 1981

Exhibit 2-10. Lewiston-Auburn CSO and Separate Storm Drain Monitoring and Sampling Locations

EXTENT OF CSO MONITORING AND PARAMETERS ANALYZED

The elements of the CSO monitoring program in each community are summarized below:

- Conducted flow metering for two 6-week periods at six CSOs in Lewiston and two CSOs in Auburn.

- Sampled the CSO monitoring locations during four significant storm events (at least 0.5 inches of rainfall with high rainfall intensity). For each storm event, a maximum of 12 discrete samples were collected during first flush and sustained flow. Initially, samples were taken at 15-minute intervals. Samples for sustained flow were collected in progressively longer time intervals (e.g., 15-, 30-, 60-, 90-minutes) depending on the anticipated duration of the overflow event. Each discrete sample was analyzed for BOD_5, suspended solids, pH, and *E. coli* bacteria. A single flow-weighted composite, prepared from the discrete samples collected with an automatic sampler for one storm event, was analyzed for lead, chromium, zinc, copper, nickel, mercury, silver, cadmium, arsenic, and TKN.

- Collected a grab sample at the CSO monitoring locations during the first flush for one storm event and was analyzed for hydrocarbons, polyaromatic hydrocarbons, PCBs, and herbicides. Specific toxic pollutants, herbicides, and hydrocarbons were selected for analyses based on available analysis methods, experience on other previous similar projects, the probability of their existence within the geographic region, and on water quality analysis industry standards.

- Conducted block testing for all CSO regulators and cross-connections in each community during the two 6-week periods that temporary flow metering was conducted to identify the frequency of CSOs to study area receiving waters.

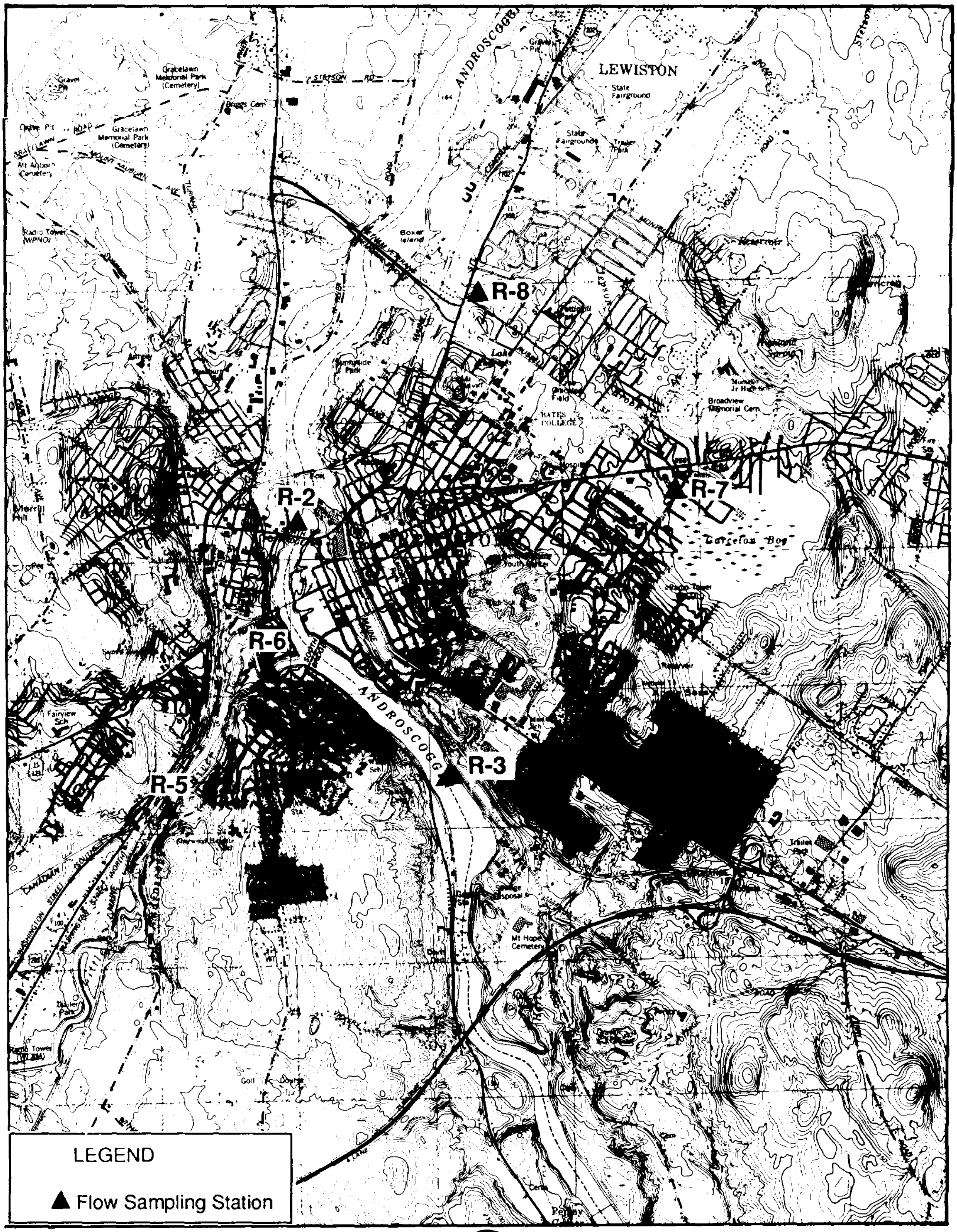
- Conducted coordinated sampling of Lewiston's and Auburn's influent flow at the treatment plant during the four monitored events. Plant personnel collected and analyzed influent samples for BOD_5, suspended solids, and *E. coli* bacteria.

The CSS was monitored using a combination of automatic samplers and hand-operated manual samplers. Continuous flow and velocity measurements in the collection system were also recorded.

SELECTION OF RECEIVING WATER MONITORING STATIONS

To assess the impacts of CSOs on the receiving waters in the study area, water quality data were collected during wet weather periods. CSOs originating from the Lewiston and Auburn sewer systems occur along the banks of the Androscoggin River and the Little Androscoggin River, as well as along drainage brooks tributary to the Androscoggin River, including Goff Brook, Gully Brook, Jepson Brook, and Stetson Brook. Sampling and monitoring were conducted at eight stations to obtain data on CSO-related water quality impacts. The receiving water sampling and monitoring stations were selected based on an examination of the receiving water use, location, importance, and the number, frequency, and relative size of the CSOs compared to that of the receiving water. Field inspections of the area receiving waters were conducted in conjunction with the field inspections of CSO regulators and cross-connections within the Lewiston and Auburn sewer systems. The purpose of these inspections was to determine the locations for sampling and monitoring of receiving waters to assess CSO-related water quality impacts.

Exhibit 2-11 shows the locations of the eight final sampling and monitoring stations for receiving waters in the study area. Four sampling and monitoring stations were selected for the Androscoggin River (stations numbered R-1 through R-4) to assess water quality impacts resulting from CSOs by both Lewiston and



SOURCE: *USGS Topographic Maps*
Lake Auburn East, Maine 1979
Lewiston, Maine 1979

3000 0 3000
SCALE IN FEET

Exhibit 2-11. Lewiston-Auburn Receiving Water Sampling Stations

Auburn. Two sampling and monitoring stations were selected for the Little Androscoggin River (stations numbered R-5 and R-6) to assess water quality impacts resulting from Auburn's CSOs to the river. Two sampling and monitoring stations were selected for Jepson Brook (stations numbered R-7 and R-8) to assess water quality impacts resulting from Lewiston's CSOs to the brook.

RECEIVING WATER MONITORING FREQUENCY AND PARAMETERS

The elements of the monitoring program for receiving waters are summarized below:

- A dry weather sampling survey was conducted, with samples collected at three lateral locations at each of the stations in the Androscoggin and Little Androscoggin Rivers. Samples were collected at only one location at each of the stations along Jepson Brook because it is relatively narrow. Samples were analyzed for *E. coli* bacteria. In-situ measurements were made of pH, dissolved oxygen (DO), and temperature. In-situ measurements for pH, DO, and temperature in the Androscoggin River and Little Androscoggin River were collected in 1-meter vertical profiles at each location. The sample for *E. coli* bacteria was collected near the water surface. In-situ measurements in Jepson Brook were not taken in 1-meter vertical profiles because the channel is relatively shallow.

- Two wet weather receiving water surveys were conducted during the same storm events that CSO sampling and monitoring were performed. Samples were collected during the two storm events at the eight stations in 4- to 6-hour intervals over a 2-day period. pH, DO, and temperature were measured in-situ. The collected samples were analyzed for *E. coli* bacteria.

- As part of the receiving water sampling and monitoring program, a continuous release dye study was conducted on one CSO from each community. The purpose of the dye studies was to evaluate the mixing and dispersion characteristics of the CSOs entering the Androscoggin River. This was accomplished by injecting dyed-water into a CSO conduit to create a simulated CSO and tracking the dye in the river using a fluorometer.

- Temporary flow monitoring at the Jepson Brook drainage channel was conducted for the duration of the sampling and monitoring program to determine the quantity of CSOs conveyed by the channel. The flow monitoring was located where the flow enters a circular conduit, and most CSOs occur upstream.

CSO AND RECEIVING WATER DATA

The collected data illustrate the quality of wastewater flow during dry weather, CSO and storm water flows during wet weather, and receiving water quality during both dry and wet weather. The data indicate impacts on receiving water quality from storm-induced CSOs and storm water discharges. Violations of the *E. coli* bacteria standards in the area receiving water are widespread during wet weather conditions and, to a limited extent, during dry weather.

CSO Data

Wet weather flow and quality data were collected during three storm events and, as indicated Exhibit 2-12, were analyzed for BOD_5, TSS, and *E. coli* bacteria. The data are within typical ranges for CSO quality and generally show a "first-flush" phenomenon. In addition, the collected samples from one storm event were composited and analyzed for selected metals, nutrients, PCBs, herbicides, and hydrocarbons. No PCBs or herbicides were detected in any of the CSO samples. The composite samples were also analyzed for a series of metals (see Exhibit 2-13), which are often present in runoff and CSOs.

Exhibit 2-12. Lewiston-Auburn CSO Quality Data

Location	BOD$_5$, mg/l		TSS, mg/l		*E. coli* Range
	Range	Average	Range	Average	Colonies/100 ml
Auburn					
CSO 002	41 - 139	43	40 - 200	111	$9.0x10^4$ - $2.1x10^6$
CSO 005	13 - 110	43	38 - 276	108	$1.1x10^5$ - $2.7x10^6$
Lewiston					
CSO 004	5 - 151	59	4 - 230	101	$5.0x10^3$ - $1.3x10^6$
CSO 007	12 - 139	52	28 - 310	123	0 - $7.0x10^5$
CSO 012	5 - 50	25	55 - 144	98	$2.0x10^4$ - $8.8x10^5$
CSO 015	4 - 6	5	21 - 28	25	$6.0x10^4$
X-2	4 - 21	12	14 - 48	34	$1.2x10^5$ - $1.1x10^6$
LAWPCF					
Structure B	31 - 195	25	72 - 200	129	$3.7x10^3$ - $1.2x10^6$
Typical CSO Characteristics[a]	60 - 220	--	270 - 550	--	$2.0x10^5$ - $1.1x10^6$

(a) Source: Metcalf & Eddy, Inc., 1991

Exhibit 2-13. Lewiston-Auburn CSO Metals Data

Parameter	Data Range (mg/l)	EPA Freshwater Acute Criteria (mg/l)
Arsenic	.0011 - .0022	.36
Cadmium	.0002 - .0019	.0039
Chromium	.0040 - .0085	.016
Copper	.07 - .15	.018
Lead	.0213 - .0810	.0830
Mercury	<.0002 - <.0004	.0024
Nickel	.002 - .006	1.400
Silver	.0008 - .002	.0041
Zinc	.09 - .13	.12

Receiving Water Data

Wet weather data were collected during two storm events where CSO and storm water sampling were also conducted (Exhibit 2-14). *E. coli* bacteria levels increased significantly in the Androscoggin River during both events. At Station R-1, the upstream station at Gulf Island Pond, little to no bacteria were detected in the samples during either storm event, indicating negligible bacterial contamination entering the study area from upstream areas. During the course of both storm events, bacterial concentrations at the downstream stations on the Androscoggin River were elevated in response to the storm-induced CSOs and storm water discharges.

DO and pH also exhibited a measurable response to the storm-related discharges. In general, when the peak levels of bacteria were observed, the DO levels declined to the lowest values and then rebounded. The variation in DO was generally less than 2 mg/l and, even at the lowest levels, DO was well above the Class C standard of 5.0 mg/l. By contrast, pH exhibited the opposite trend from the dissolved oxygen data. The pH levels generally climbed in response to the storm event.

At the downstream station of the Little Androscoggin River, significant levels of bacteria were measured during the peak periods of the September storm. These levels exceeded the Class C criterion, reaching concentrations of 8,000 colonies/100 ml. The high levels did not persist for an extended period of time. In the October storm, the bacterial levels increased as a result of the storm-induced CSOs, but not to a level that exceeded the Class C criterion.

DO at both stations on the Little Androscoggin indicated a noticeable sag in response to the storm-induced CSOs. Oxygen levels at both stations are normally elevated due to aeration as a result of the dams immediately upstream of each sampling site. DO concentrations declined by approximately 1 to 2 mg/l in the September storm, while less sag was observed during the October storm. During both storm events, the DO sag was temporary, with the oxygen concentrations returning to pre-storm conditions relatively quickly. Because both upstream and downstream stations exhibited the DO sag and increase, upstream influences appear to have a significant impact on oxygen levels.

The highest *E. coli* counts measured in the receiving water sampling program were detected in Jepson Brook. Bacteria levels at both sampling stations exceeded the Class B criterion of 427 colonies/100 ml during the two storm events. Levels of *E. coli* rose significantly in response to the storms. This was expected for the downstream sampling station, Station R-8, due to the number of CSO outfalls and storm drains discharging to the brook. The elevated *E. coli* levels at the upstream end of the brook were not anticipated, however. Similar levels were observed in both storm events.

DO levels exhibited a decrease in response to the storm events. The dissolved oxygen sag was significant, as the lowest value for oxygen measured was 5.0 mg/l, well below the Class B criterion of 7.0 mg/l.

The wet weather receiving water data clearly indicated the impacts of CSOs and storm drain discharges on the local receiving waters during storm events. These data, together with the background dry weather water quality data, CSO and storm drain flow and load data, and the continuous dye study, provided the basis for the CSO and receiving water modeling effort described in the next case study, following Section 2.6.2.3.

Exhibit 2-14. Lewiston-Auburn Receiving Water *E. Coli* Data

Station	Dry Weather		Wet Weather			
			September 26-28, 1993		October 12-14, 1993	
	Range (colonies/100ml)	% of Samples Above Standards	Range (colonies/100 ml)	% of Samples Above Standards	Range (colonies/ 100 ml)	% of Samples Above Standards
Androscoggin River						
R-1	0	0	0 - 20	5	0	0
R-2	480 - 2,280	67	0 - 1,440	8	0 - 980	4
R-3	100 - 135	0	160 - 6,800	58	10 - 3,500	25
R-4	280 - 355	0	60 - TNTC	71	90 - TNTC	29
Little Androscoggin River						
R-5	5 - 115	0	0 - 810	0	0 - 210	0
R-6	35 - 80	0	0 - 8,000	17	0 - 280	0
Jepson Brook						
R-7	60	0	20 - 2,400	33	40 - 2,500	31
R-8	115	0	40 - 30,000	83	140 - TNTC	62

Note: Class C Standard: Instantaneous level of 949 colonies/100 ml
TNTC = Too numerous to count